Microstrip Reflectarray With Elements Having Variable Rotation Angle.s"

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Introduction: Two Ka-band, half-meter diameter, circularly polarized microstrip reflectarrays have been developed, One has identical square patches with variable-len~th phase delay lines. The other uses identical square patches and delay lines with variable element rotation angles. Although both antennas demonstrated excellent efficiencies, adequate bandwidths, and low aver-age sidelobe and cross-pol levels, the one with variable rotation angles achieved superior overall performance. It is believed that these are electrically the largest microstrip reflectarrays (6924 elements with 42 dB gain) ever developed. It is also the first time that circular polarization has been actually demonstrated using microstrip patch elements. Recent advances in reflectarray technology include the following; An X-band 0,75 m diameter microstrip reflectarray [1] using variable-length phase delay lines which demonstrated a relatively high efficiency of 70% with peak gain of 35 dB; a partial microstrip reflectarray with beam scanning capability [2]; A 27 GHz 0.23m diameter microstrip reflectarray using variable-size patches [3] which achieved a gain of 31dB at an efficiency of 3 1%0, All these reflectarrays have dual-linear and dual-circular polarization capabilities, but only linear polarizations were demonstrated.

It is known that, if a circularly polarized antenna element is rotated from its original position by ψ degrees, the phase of the element will be either advanced or delayed by the same ψ degrees. Hence, the technique of rotating circularly polarized demerits to achieve the required phases for a conventional array to scan its bear-n has been previously demonstrated [4]. This technique was also demonstrated for a spiraphase reflectarray [5] where physically large spiral elements with discrete and limited switchable phase states were. used to scan the beam. here small and low-profile printed microstrip elements are used in a reflectarray with continuous variable angular rotations to achieve far-field phase coherence, It has been proposed [6] that a controllable miniature or micro o-machined motor can be placed under each patch element of a reflect array to scan the beam to wide angular directions. By doing so, the high-cost/high-loss phase shifters, T/R modules, and beamformer are no longer needed in a beam scanning antenna.

Analysis, Design, and Measurement Results: Consider the case as shown in Fig. 1 where the two transmission phase delay lines connected to the square patch are of unequal length, l_x and /Y, but where the lengths and patch size are uniform across the reflectarray aperture, With a left-hand CP incident wave and l_x longer than /Y by 90° of phase, the array analysis result shows that the reflected wave remains left-hand CP. But the field reflected from the patch in Fig. 1 (b) has a p'base delay of 2ψ degrees longer than that reflected from the patch in Fig. 1 (a), The analysis aiso shows that a right-hand CP incident wave, upon reflection, has a phase advancement by 2ψ from the patch in Fig. 1 (b).

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Two circularly polarized microstrip reflectarrays were designed at the frequency of 32.0 GHz. Each one has a diameter of a half meter and 6,924 square patch elements. One has identical patches with variable-length phase delay lines. The other one, shown in Fig. 2, also uses identical patches but with variable patch rotation angles, Both antennas have elements etched on Duroid substrate with 0,25 mm thickness and 2.2 relative dielectric constant. With this substrate, the calculated single patch bandwidth is about 4%. Both antennas were designed for broadside radiation with the same f/D ratio of 0.75. The element spacing is 0.58 free-space wavelengths which was determined by analysis to avoid grating lobes, The width of all phase delay lines (0.075mm) are designed to have an impedance of 150 ohms. In order to achieve the flatness (0.3mm) required at Ka-band across the half-meter aperture, the thin substrate is supported by a 1.9cm thick aluminum honeycomb panel, A photo of the antenna is given in Fig. 3. 'l'he feed horn, a corrugated CP conical horn, was designed to illuminate the reflectarray aperture with a -9 dB edge taper, The purpose of the horn's corrugation is to reduce sidelobes for lower spillover loss and to seduce cross-pol level. 'The radiation pattern of the unit with variable-length phase delay lines (named unit 1) measured at 32,0 GHz if given in Fig. 4 which shows a peak sidelobe of -22 dB and all other sidelobes, except the first two, are well below -30 dB. This measured elevation pattern is pretty much the same in different azimuth planes of the antenna, 'l'he two high sidelobes next to the main beam are believed to be caused by the feed blockage. All cross-pol radiation, except in the main beam region, is well below -40 dB level. The relatively high cross-pol of -22 dB in the main beam is caused by the co-phasal behavior of the cross-pol components of the patches and the cross-pol of the feed horn. In other words, the cross-pol, similar to the co-pol, fields are ail coherently directed to the same direction by the same set of phase delay lines. The pattern of the unit with variable rotation angles (named unit 2) is shown in Figure 5. It shows a peak sidelobe of -22 dB due to the same feed blockage. All the other sidelobes, except the. first few, are well below -40 dB, which is significantly lower than those of unit 1. Its cross-pol radiation, except one lobe at -28 dB, is ail below -30 dB. The single high cross-pol lobe in the main beam of unit 1 has now disappeared and is distributed over a wide angular region, The major reason that unit 2 achieved lower sidelobe anti cross-pol levels than those of unit 1 is the diffuse, instead of the co-phasal, scatterings by the near randomly rotated patches and lines

The unit 1 reflectarray has a measured gain of 42.75 dB for an overall antenna aperture efficiency of 690/. at the frequency of 31.5 GHz. It's bandwidth behavior is given in Fig. 6 where an oscillatory response is observed. It is believed that, in addition to the resonance of the patches, some of the delay lines also become resonant at some frequencies since their length dimensions vary and become close to those of the patches. The resonances of these lines add in-and-out of phase with the resonance of the patches over the band of interest and thus form the oscillatory behavior. The measured gain of unit 2 has a peak at 31.7 GHz anti is 42. ? dB for- an efficiency of 60%. "l'he bandwidth response of unit 2 is presented in Fig. 7 where it shows a -1 dB-gain bandwidth of 1,1 GHz (3.50/.) and a -3 till-~ain bandwidth of 1.7 GHz (5,40A), Notice that the oscillatory behavior has diminished for unit 2. This is because not oniy do all the patches of unit 2 have identical phase delay lines but aiso they appear to be randomly rotated. As a result, it is not likely the phase delay lines of unit 2 could resonate with the patches in-anti-olit of phase many times across the frequency band. To summarize, the unit 2 antenna, by using variably rotated elements, achieved overall better performance than that of the unit 1 antenna. It demonstrated lower sidelobes, lower- cross-pol, anti better bandwidth behavior.

References:

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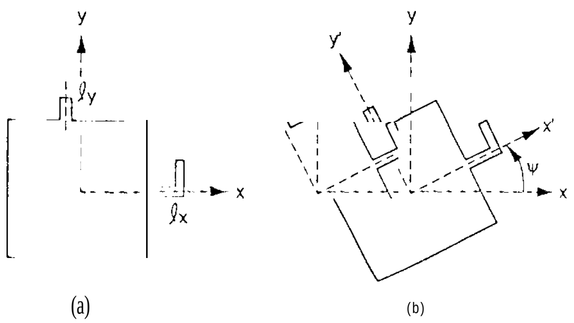

Figure 1. Circularly polarized reflectarray patch element; (a) 0° phase shift reference element, (b) rotated element with 2ψ-deg phase shift.

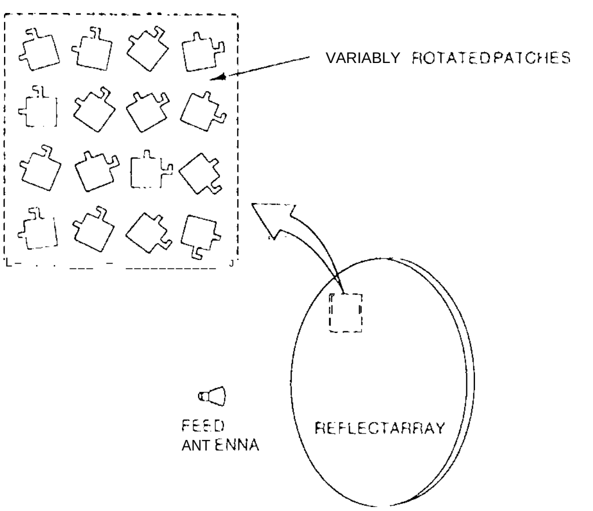

Figure 2. CP microstrip reflectarray with elements having variable rotation angles.

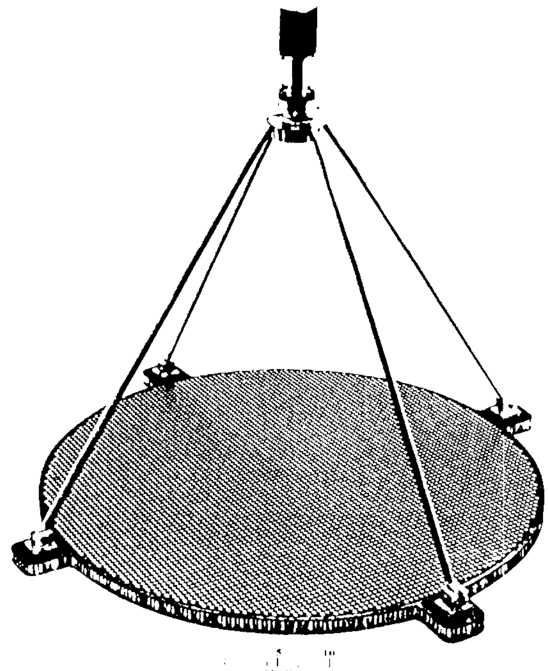

Figure 3, Photo of 0.5m Ka-band microstrip reflectarray with elements having variable rotation angles.

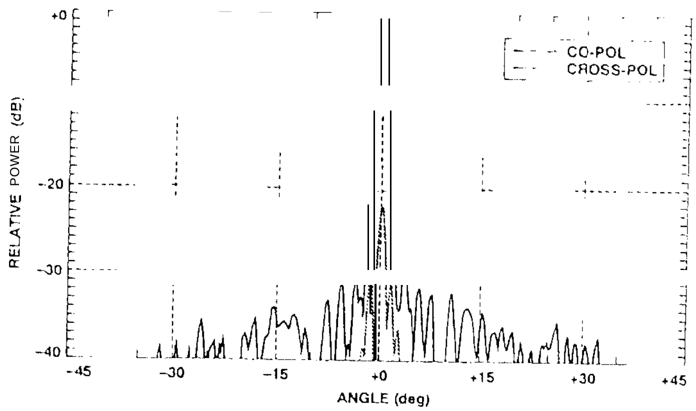

Figure 4. Measured pattern of reflectarray with patches having variable-length phase delay lines.

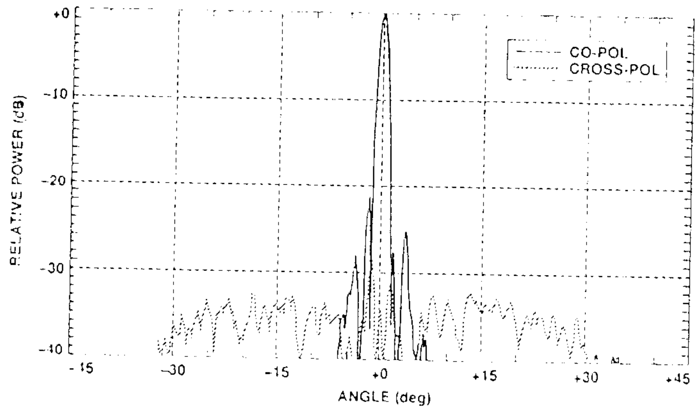

Figure 5. Measured pattern of reflectarray with patches having variable rotation angles.

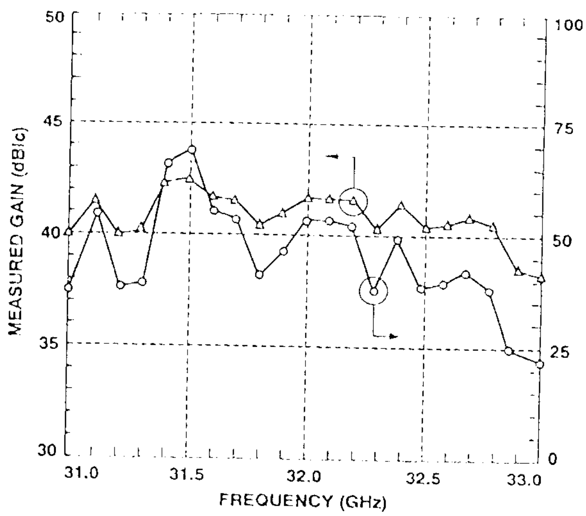

Figure 6. Measured bandwidth performance with patches having variable-length phase delay lines.

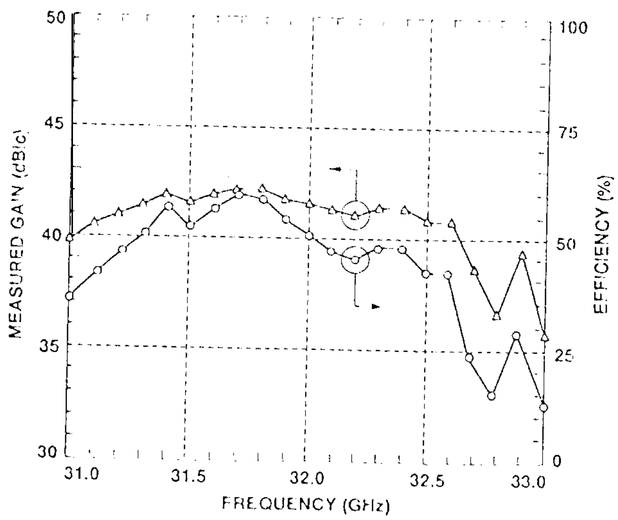

Figure 7. Measured bandwidth performance with patches having variable rotation angles.